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RELATIONS OF THE CEREBRAL CORTEX TO SENSATION.[1]

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EVERY marked advance in our knowledge of the structure of the nervous system is of interest to the practical physician because of its bearing upon the understanding of nervous function, as this in turn offers the only prospect for the correct interpretation of nervous derangements. In comparison with the histological investigation of nervous tissues the minute structure of any other tissues, even the most complex, is simplicity itself. We cannot, therefore, appreciate better what recent progress in this respect amounts to than by noting at what a stand-still investigators found themselves but a few years ago when the most patient dissection and microscopic observation seemed to terminate, as far as the gray matter was concerned, in a totally unravelable maze of minute, soft, interlacing threads, which, especially in the cerebral cortex, seemed to increase out of proportion to the cells, but in direct proportion to the presumable rise in grade of function. An insurmountable obstacle, therefore, purely physical in its nature, appeared to forbid any prospect of further penetration to the ultimate facts of nervous anatomy.

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[1] Read before the New York Neurological Society, April 2, 1895.

On the other hand, the knowledge so far gained seemed to point to the following conclusions:

1. The chief element in nervous matter is the ganglion.
2. The chief element in a ganglion is its cells.
3. The nerve fibres are simply channels of transmission to and from cells.
4. That certain associations of ganglia made to act together by commissural connecting fibres, constituted "nerve centres" endowed with special functions.
5. That these functions were carried out by corresponding tracts of nerve fibres.
6. That the nerve fibres themselves either made anastomoses between cells or were lost in an intercellular granular matrix.

It is not needful for me to describe to such an audience as this the methods by which the slenderest threads of nervous protoplasm have been made separately to show themselves, and thus to be tracked, however devious their intertwining and ramifications with other fibres. Golgi's staining, aiding also the further prosecution of Fleschig's developmental method, and Marchi's staining of degenerating tracts, have carried on to a point where some conclusions seem well nigh demonstrated, which, as we compare them with the previous views, cannot but modify in more than one respect our whole conception of nerve function. These conclusions in brief are:

1. That the anatomical unit of the nervous system is neither a ganglion nor a cell.
2. That a nerve fibre is not simply a channel of transmission.
3. That the anatomical unit of the nervous system is a cell with its process or processes, these together constituting an anatomical entity which has no direct or anastomatic connection with other nervous cells or processes. All relations of this anatomical nervous unit with others are physiological relations through proximity or contact, and not by fusion of fibres.
4. Therefore, the origin and seat of nervous function are not restricted to the cell, but rather are so far shared by its processes that it has even been surmised that the cell has for its chief office to maintain the nutrition of the processes, and to influence the direction, rather than solely to originate function. Hence, the development and elaboration of function would seem to be dependent

more upon the development of the protoplasm of the processes than upon the development of the cell itself.

These conclusions are based upon the consideration of the anatomical unit itself, viz., a nerve cell and its processes, to which Waldeyer has given the name neuron. Considering how desirable it is to have our conceptions kept definite as to the fundamental facts of nervous structure and function, it is a pity that Waldeyer's term has already been modified in its applications by various writers. Thus Schäfer restricts "neuron" to the axis cylinders processes of cells, while to the branching processes he applies the term "dendrons." As the most important proposition, regarded from the physiological point of view, is that the cell and its processes always constitute a concrete unity, or a nervous system, so to speak, by itself, it would seem best to keep some term simply to designate this fact, as Waldeyer originally proposed with "neuron," and which is good enough, pace some etymologists in Greek, for this purpose; while other terms might be devised for the neuron's constituent parts.

One of the chief deductions from these investigations seems to me to be a more definite conception of the plasticity of nervous matter. Instead of being confined within the exclusive limits of a nerve cell, we appear to have an active expanse of nerve matter and of nervous function reaching to the extremest peripheral distribution on the one hand, and similarly profoundly operative around the inner cells on the other, constant reaction and interaction between the terminal arborescent expansions at both ends taking the place of simple centric transmission in either direction.

Some interesting questions, therefore, now arise. 1. If no cell in the nervous system exists without process or processes, and as each cell with its process or processes constitutes an anatomical unit, by what means do these units become so interacting as finally to become organized to perform certain special functions together? 2. To what extent does such organization of special collections of neurons merit the term "nerve centre" being applied to them? 3. Does precedence in such organization in order or in time of development, as in the spinal centres, give greater fixity to such organization so as to afford justification for applying the term centre only to such seats of function, while to others of later development, as in the cerebral cortex, this term ceases to have the same application on account of the greater plasticity of their elements, allowing more latitude in function according to the temporary training of individual life rather than the permanent hereditary organization of the spinal centres? The specially trained regions of the cortical centres in man, both afferent and efferent, connected with the function of speech and which are neither original nor hereditary in their capacity for speech, being illustrations in point.

To the first question, how does any given collection of neurons become so organized to work together as to perform a specific function, the recent advances seem to emphasize the fact all the more, that recurrent afferent impression on the extremely plastic peripheral termini until they become habitual, or normal in the etymological sense of the term; that is, according to rule, are the primary and essential sources of nervous organization from the simplest to the most complex examples of such organization. As the simple sensitive ectodermal cell in the hydra with but a single process proceeding direct to a contractile fibre within, is one of the earliest manifestations of nervous function, so each step in more complex organizations seems but a further and further development of the effects of afferent impressions. Afferent habit, in other words, is the origin of every nervous habit, *i. e.*, special function, whether in single neurons or among associated neurons. In time, habitual impressions, followed by corresponding habitual reactions, become opposed to non-habitual impressions, and thus give origin to the great function of inhibition, without whose constant influence no permanent organization would be possible. Under the old view it was the inner cells which became thus organized in response to afferent impressions which were radiated from cell to cell through commissural fibres, which thus became established tracts of intercellular impulses. The new view gives us more reason to apportion a larger share to the plasticity of peripheral nervous protoplasm. In fact, it is not easy to limit the degree of that plasticity for acquiring function. We seem to have, for example, in the nervous mechanism of the earthworm a simple division between the sensitive cells of its epidermis and the motor cells of its axis, with but a single connection between. And yet so varied has the peripheral protoplasm become in its susceptibility, that the worm, with neither eyes nor ears, yet evidently reacts both to light and to sounds. From considerations to be adduced soon, it does not seem illogical to infer that cortical gray matter is likewise a plastic " peripheral expansion " and that the only relatively stable and non-plastic centres are the spinal centres.

But does any different principle or law of development enter into the organization of the spinal segments of vertebrates? We do not see the slightest reason for such a supposition. Nor would there be any occasion for such a supposition but for the gradual development, as we ascend to the upper segments of the cord, of newer and special manifestations of the afferent apparatus which oblige us to apply to them the elastic and portentous term sensation, not as a modification of afferent impression simply, but as introducing us to the boundless realm of consciousness and psychics. But where and when does an afferent impression become truly "sensory" and thus pass into a sensation and that to a definite consciousness? Does the entrance of this psychic element imply any new arrangement of nervous elements in any particular region or place, which, therefore, may be called the seat of sensation, or the area of sensation?

The answer to this question should not be sought in an examination of the functions, local or general, of the cerebral cortex, for that would be attacking the problem by dealing first with much its most complex aspect. Instead it should be insisted upon that experimental research does not oblige us to go any higher than the spinal system proper to locate the whereabouts of sensation, whether of a general or of a special character. We approach the confines of sensation instead by gradual stages through a series of wonderfully organized collections of spinal neurons, which have learned to work together so thoroughly that they have all the perfection of complete consciousness and purpose in that working. The headless body of a frog can be made to behave as if the head was still there. It is to be particularly emphasized that no cerebrum is needed to fill out all the requirements that can be asked in the way of evidence that sensation, and action dependent upon sensation, are already present. This is proven by removing the cerebrum and noting what functions remain.

To begin with, osseous fishes, such as the carp; when the ganglia which in them correspond to the cerebral hemispheres, are removed, there is little, if anything, to distinguish them from normal animals. They maintain their normal attitude and use their tails and fins in swimming with the same vigor and precision as before. Lest this be considered as only equivalent to the unconscious spinal adjustments in the body of a decapitated frog, the experiments of Vulpian and Steiner with the fishes show not only that they are still able to see, but that they also can find their food. If worms are thrown into the water in which they are swimming, they immediately pounce upon them. If a piece of string similar in size to a worm be thrown in, they are able to detect the difference and they drop it after having seized it. They even to some extent distinguished colors; for when one red and some white wafers are thrown into the water, the fish almost invariably selects the single red one in preference to the white. So also with the frog. In Schrader's experiments, frogs which recovered from the ablation of their cerebral ganglia behave then like full brained frogs under like circumstances. They crawled under stones or buried themselves in the earth at the beginning of winter, and after the period of hibernation was over they came out and diligently caught the flies which were buzzing about in the vessels in which they were kept. Rising in the scale, Schrader's and Von Recklinghausen's experiments are too well known to detail about birds, who, without cerebral ganglia not only avoided obstacles in their path or in their flight and would fly from one place and alight securely on another, but were quick to ruffle feathers and to show fight when put in the proper position with other birds.

I do not see, indeed, how the position of some neurologists about the exclusive relations of the cerebral cortex to sensation, which we shall allude to presently, can be fully maintained in view of the published experiments of Goltz upon dogs, except by showing that Goltz's dogs differ from all other dogs. No number of negative results will disprove the positive results which Goltz reports and which he maintains are the only trustworthy observations yet published in their bearing on the questions raised, because the dogs survived the operation long enough to have all the vitiating effects of the primary injury pass off. In his seventh communication *Archive für Physiology*, Vol. v., p. 570, Bonn, he details his success in removing the entire cerebrum without killing the dog. The animal was kept alive for eighteen and one-half months, and post-mortem examination showed that all the cortex had been removed, except from a small portion of the basal surface of the top of the temporal lobe. In addition to the cortical lesion, a large part of the corpora striata and thalami and a small part of the mid-brain had been destroyed. The small remnant of the temporal cortex not actually destroyed was, of course, practically removed, since all its peripheral connections had been interrupted. This animal slept naturally and could be awakened by loud noises or by handling. Strong, painful stimulation of the skin caused him to bark or growl, or even to snap. In making this last movement he turned in the proper direction to left or to right. He was able to maintain his equilibrum properly when one foot was placed on a falling trap door. He was able also to move round on three legs. He also closed his eyes when a bright light was thrown upon them. He ultimately learned to eat and drink provided his nose was brought into contact with the food. That he would also taste was shown by his invariably rejecting food moistened with quinine, after chewing it for a while. He also showed unmistakable signs of hunger or of thirst when deprived for some time of food and drink, and the eagerness with which he took the food when it was afterwards given to him was full proof of his hunger sensations. Goltz, therefore, comparing his dogs with the pigeons of Schrader and the fishes of Steiner, maintains that the mechanism of the cord and portions of the brain posterior to the cerebrum are approximately identical in all higher vertebrates, and that his dog without a cerebrum compared with a normal animal showed defects only in the manifestation of intelligence, memory, reflection and understanding; that is, in what are called the higher psychical functions.

In his other experiments the same conclusions are just as fully borne out, though in none did the animals survive as long as this one. In view of these facts, it certainly is difficult to deny that in these lower portions of the nervous axis, speaking relatively to the cerebrum, we have all the conditions which can be supposed necessary to constitute true nervous centres or seats of sensation. We have undoubted manifestations of the presence of every variety of sensation, tactile, muscular sense, sense of pain, vision, hearing, taste, and finally the visceral sensations of hunger and of thirst. Moreover, from the very limited areas of gray matter in these parts compared with the great expanse of the cerebral cortex, the conception of definite and strictly limited collections of neurons subserving special functions for which they have been permanently and heriditarily organized as the "centres" of such functions, is much clearer than can be predicated of any portion of the outer cerebral layers.

On the other hand, it cannot be denied that both experimental and pathological observations show that certain areas of the cerebral cortex have special relations to both sensation and motion. The question now is what is that relation? Is it a transfer of sensation from a lower to a higher seat, or is the seat of sensation proper still in the lower level, while the corresponding cortical function is for the cortical interpretation, so to speak, of the activity of the lower centres? It is evident that if a sensation has anything to do with a cerebral process that then it will have other elements in it than if it partook only of elements in the processes whose seat was in the ganglia of Goltz's dog. A cerebral process of sensation, in other words, would certainly include a cerebral recognition of the nature and character of the sensation as well as the sensation itself. By the influence of long habit, however, it would become very difficult so to analyse this cerebral act of sensation as to separate its cortical from its non-cortical elements. A sudden suspension, therefore, of cerebral sensation would involve so much loss of its habitual accompaniments as to appear to amount to complete suspension of sensation itself. A complete abolition of sensation, however, would be a permanent effect, if sensation had its true seat in a cortical area. That it is not so is Goltz's contention. All he asks is that time enough be allowed after any lesion in a cortical area to show that such lesions, however extensive or complete, nevertheless do not abolish either sensation or motion.

The readiest way it seems to me whereby to arrive at practical conclusions about the relations of cortical areas to these functions is to take into consideration, first, some general facts about the anatomical organization and sequence of development in function of the cerebral cortex itself. In fœtal life the cells of the layers of the cerebral cortex are both small and closely packed together. The cell bodies up to a certain age (Andriezen)[2] seem to grow in size, but that limit is soon reached while the animal is still young. But meanwhile the cell bodies certainly seem to get further apart during early life, much more so than their slight increase of size would be adequate to account for, and which, therefore, used to be explained by various authors as due to increase of blood-vessels, of neurolgia or of ground substance. But recent discoveries demonstrate that this phenomenon is correlated not with the growth of non-nervous structures pushing the nerve cells further apart, which cells, by the way, seem to cease to grow in number after early life, but by a progressive increase in the intercellular protoplasmic nervous dendrons or fibres of the cells. This growth in the extent and complexity of connections of the protoplasmic processes of the brain cell, both basilar and apical, causes the cells which in intra-uterine life lie so closely packed as to touch each other, to separate more and more widely until in the adult they seem to have become relatively quite sparse. We find in this anatomical fact certainly a strong presumption that the cerebral cortex grows in functional capacity by greater increase and elaboration of its nerve matter, though not of its cellular elements. Corresponding to this capacity for growth of its intercellular elements appear certain developments of functions in the cerebral cortex which are markedly different in genesis from anything which can be predicated of the special centres, in that they are newly acquired during individual life and are thus incapable of hereditary transmission. This fact so significant of the true relations of the cerebral cortex to function, is well shown in the acquisition by certain cortical areas in man of such highly specialized functions as sensory and motor speech. What the plasticity for acquiring function must be in this case is further shown by its localization in only one hemisphere, evidently through habit alone, determined in the first instance by the greater use of the right hand in gesture language. The corresponding areas in the other hemisphere, not being used, remain functionless in this respect. The phenomena of word-blindness, for example, following upon a lesion of a particular anatomical area is certainly a sufficient demonstration of the educability rather than of the inherent capacity of cortical matter for subserving function, because in this case this function was acquired long after all other cerebral functions had become settled and organized. A person learns to read and write, or rather his particular cortical area, therefore, learns to do so, not by reason of any particular endowment of that area for that purpose, but solely because it has been made to learn it by repeated afferent and specifically guided impressions coming through the eye. No doubt also that later still in life, the protoplasmic dendrons of the central arborescent terminations, in the cerebrum, of the tactile nerve, become just as specially organized in the blind who learn to read by the raised letters provided for them.

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[2] *Brain*, 1894, p. 639.

The bearing of these considerations on the origin of the relations of the Rolandic areas to sensation and to motion is obvious. They show that we need not predicate any original or necessary connection of these areas with either sensation or motion. When a child learns to use its hands or its feet, it is just as likely while doing so to be developing special cortical areas for sensation and for motion, which may not originally have been endowed with those functions, as it afterwards educates certain areas of its left hemisphere to hear words, others to see words, and others still to express words. Certainly its attempts to learn to use its hands and its feet require just as protracted, repeated and laborious effort as its subsequent efforts to learn speech, which latter end in particular modifications of its cerebral cortex. Why, therefore, may not the sensory and motor functions of the Rolandic convolutions be as much acquired as the sensory and motor speech convolutions acquire their functions?

If this be so, we then can perceive that the educability of the cortical gray matter is such that probably in no two persons are the special areas corresponding to special functions exactly the same in extent. In one the respective areas may considerably overlap the boundaries of the equivalent areas in another. Such overlapping, indeed, probably has been already demonstrated in the motor areas, for Sherrington has found degeneration fibres in the pyramidal tract extending as far as the lumbar region following upon a lesion of the so-called cortical arm centre. On the other hand, the intimate blending of afferent or sensory, and efferent or motor elements in the Rolandic area is just what we should expect if these parts have been educated to their business. Motion is here immediately dependent upon, and directed by sensation as nowhere else in the nervous system. Respiratory (spinal) movements may be rhythmical, but phonation (cerebral) movements must be immediate, and so with the rest. On the other hand, in the cortex itself the areas related to the sensory functions of sight and of hearing might relatively be considerably removed, as we find them, from the motor structures. So also the close blending of the functions in the Rolandic area is illustrated by the common occurrence of the sensory phenomenon of allochiria along with motor paresis.

We conclude, therefore, that, properly speaking, there are no centres for either sensation or motion in the cerebral cortex. Such terms should be restricted to the structures which correspond to Hughling Jackson's lower level of the cerebro spinal system. The cerebrum acquires its functions, however related they be to sensation or to motion, by education rather than by intrinsic endowment, and this fact accounts both for the comparatively indeterminate boundaries of its functional areas, and for the temporary nature of the effects of lesions in them. As Waller remarks, "The clinical history of a dog or of a monkey having suffered a removal of some part of the Rolandic area altogether negatives a strict limitation of function, and at most suggests its local concentration. Even clumsiness is not apt to be permanent. We thus picture the cortical organ in a semi-fluid state of differentiation, still variable by new instruction, rather than a petrified and invariable collection of specialized organs tied down to particular functions."

The death of B. Hack Tuke is announced in recent journals. There is probably no one name so well known to alienists, and again there is no one name among the lists so prominent for kindly, benevolent, uncritical spirit of helpfulness His life was one impaired by ill-health, and his writings are therefore more remarkable from this fact. The Dictionary of Psychological Medicine, which bears his name, will be a fitting monument to carry his fame and influence to his successors. The patient and continued unselfish labor which is represented tells clearly enough the spirit of the man.